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OF Q-SWITCHED RUBY LASER

by

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STUDY OF RETINAL INJURY THRESHOLDS
OF Q-SWITCHED RUBY LASER

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ABSTRACT:

Abstract: The thresholds of retinal injury of rabbit eye is experimentally determined, by means of exposing the eye to Q-switch ruby laser light. The results show that the coaglating-bleeding threshold (ED_{50}) of retinal injury is 361μJ/cm², the bleeding damage threshold (ED_{50}) is 481μJ/cm². The 95% confidence levels are 330μJ/cm²~394μJ/cm² and 451μJ/cm²~514μJ/cm², respectively.

I. Introduction

The ruby laser is the earliest and most extensively used laser with wavelength at 694.3nm. The retina readily absorbs this wavelength, thus easily causing retinal injury that even leads to blindness. Therefore, the study of eye injuries caused by the ruby laser has practical significance in regard to laser-caused injuries and safety practices. This paper reports on a study of the threshold values of rabbit retinal injury caused by a dye Q-switched ruby laser to provide biological data on injuries caused by laser waveband selection.

II. Experimental Installation and Method

The illumination equipment used in this experiment was the Q-switched dye ruby laser device assembled by the authors, consisting mainly of systems of collimated light, ruby rod, resonant cavity, dye Q-switching and polarized compensation, as well as attenuation lens and diaphragm (Fig. 1). The maximum output energy of this laser was 220mJ with a pulse width of 48ns. The energy instability was approximately ±5%, and the divergence angle was 3 to 5mrad.

The model NJ-J1 laser energy meter was used for level measurements with beam-splitting illumination for polarized compensation and the real-time energy monitoring method. All instruments used were calibrated by the National Academy of Metrology; the error coefficient of measurement standard was ±0.9 to 4.3%.

The experimental animals were blue, purple and gray rabbits with body weights between 2 and 3kg. The experiment only used those rabbits which were normal when examined with an eye inspection lens. Ten to 15min before illumination with the laser, the rabbits' pupils were delated with 0.5% tropine amide. Then these rabbits were anaesthetized with intramuscular injection of 5% thiamine ketone at 25 to 30mg/kg. During laser illumination, a He-Ne laser providing the collinear optical path

was used as the collimated light source with an OD6mm diaphragm to restrict the light beam. Passing through a reflection lens, the laser beam was illuminated onto the rabbit eye fundus. Observed with a Topcon eye-fundus camera, the laser beam was directed at the lower side of the papillary portion of the optical nerve root behind the retina. One hour after laser illumination, the rabbit eye fundus was examined with an eye inspection lens to record the number of lesion spots; the examination results were checked by more than two inspection personnel. Some rabbit eyeballs were surgically removed for pathological tissue examination. Altogether, 60 eyes (354 sampling spots) were illuminated with the laser during the experiment for statistical data on various level groups for retinal coagulatory bleeding rates and bleeding-only rates. By means of weighted regressive statistical computer processing of the experimental data, ED_{50}, of retinal coagulatory bleeding rates and bleeding-only rates were obtained.

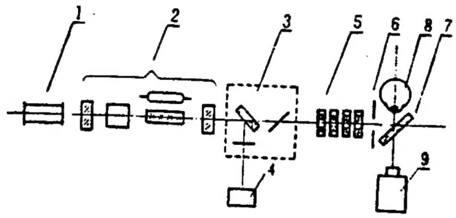


Fig. 1 Optical path of Q-switched dye ruby laser illumination device

Legend:
1 - He-Be collimated light
2 - Ruby laser device
3 - Polarized compensation system
4 - Monitoring energy meter
5 - Attenuation lens
6 - Diaphragm
7 - Reflection lens
8 - Rabbit eye
9 - Camera for eye fundus

a 实验分组	角膜平均辐照量 b (μJ/cm²)	照射 c 点数	凝固出血 d		出血 e	
			反应点数 f	%	反应点数 f	%
1	704	54	49	90.7	49	90.7
2	583	60	48	80.0	36	60.0
3	447	60	33	55.0	29	48.3
4	319	60	26	43.3	6	10.0
5	248	60	19	31.7	3	5.0
6	162	60	4	6.7	0	0

Fig. 2. Relationship between illumination levels by Q-switched dye ruby laser, and retinal coagulatory bleeding rate.

Key: a. Damage probability unit
b. Level logarithm

III. Experimental Results

There were altogether six level groups in the experiment. The range of illumination levels was 162 to 704 $\mu J/cm^2$.

1. Manifestation of retinal injury

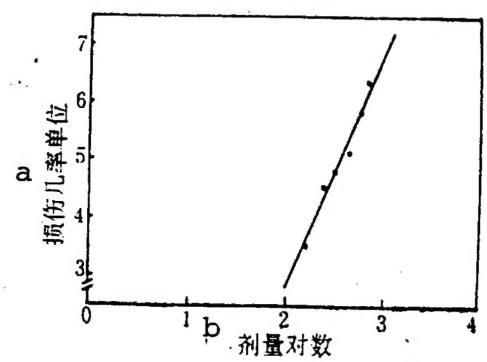
Generally, there are the following four kinds of retinal injury foci as observed with the eye inspection lens: (1) there are only grayish-white or light gray small circular retinal coagulation spots with clear boundaries. Most of these spots appeared about 10min after illumination. At 24h after illumination, some foci were manifested as sedimentation of pigment aggregation. (2) There was bleeding at the center of the coagulation spots with spreading toward the outer area. (3) There was circular or carnation-shaped bleeding at the retina. Observed from some foci, blood flowing into the crystalline lens was visible. Most coagulation lesions receded (or had residual pigment) 3 to 5 days later. Bleeding lesions began to be resorbed in about 1 week after illumination; in 3 to 4 weeks, white tissue spots were formed.

2. Relationship between illumination level and retinal damage incidence

In the attached table, the illumination levels and retinal damage incidence 1h after illumination are shown. From the table, the incidence of retinal damage increases with increase in

average incident irradiation at the cornea. When the illumination levels were within the range of 162μJ/cm^2 and 704μJ/cm^2, the incidence of retinal coagulation bleeding injury was within the range of 6.7% (4/60) to 90.7% (49/54). Along with increasing illumination levels, the retinal coagulation injury changes from an increase to a gradual decrease. However, the bleeding proportion gradually increases. For example, when the average illumination of the cornea in the lowest-level group was 162μJ/cm^2, the retinal injury foci appeared as coagulation. When the level was increased from 248 to 583μJ/cm^2, the bleeding percentage increased from 15.8% (3/19) to 75% (36/48) of all lesions. In the highest-level group of 704μJ/cm^2, all retinal lesions appeared as bleeding.

Attached Table: Illumination Levels of Q-Switched Dye Ruby Laser, and Retinal Injury Incidence



Key: a - Groups in experiment; b - Average irradiation on cornea; c - Number of irradiation points; d - Coagulatory bleeding; e - Bleeding; f - Number of reaction points

3. Calculation of threshold value of retinal lesion

In the experiment, observations were made with an eye inspection lens 1h after illumination of the rabbit retinas.

There was 50 percent probability of retinal coagulation and/or bleeding, and exclusive bleeding; the illumination level required was the injury threshold value (ED_{50}). The experimental results were regressively computed with the iterative substitution weighted probability unit method using a computer. Thus, a regression equation and the ED_{50} were derived for the rabbit retinal coagulatory bleeding lesion probability unit and bleeding lesion probability unit with respect to the illumination level logarithm of the Q-switched dye ruby laser.

The regression equation and ED_{50} of the retinal coagulatory bleeding lesion are shown in the following:

$$\hat{Y} = 3.9470x - 5.0935$$

$$ED_{50} \approx 361 \mu J/cm^2$$

(95% confidence limit $330 \mu J/cm^2 \sim 394 \mu J/cm^2$)

The regression equation and the ED_{50} of retinal bleeding lesions are shown in the following:

$$\hat{Y} = 6.2645x - 11.8010$$

$$ED_{50} \approx 481 \mu J/cm^2$$

(95% confidence limit $451 \mu J/cm^2 \sim 514 \mu J/cm^2$)

When tested with x^2, $x^2=10.2279$, which was lower than the $x_{0.05}^2$ boundary (14.076). This means that the retinal-lesion-occurrence probability unit was linearly related to the illumination level logarithm (Fig. 2).

4. Pathological changes in retinal lesions

Mainly, there are the following three types of retinal lesion observed through the lens: (1) exudates from the retina: the retina was convex or slightly convex in shape. The visual cell layer was thickened with edema having fracture at the outer

node, forming a cavity gap with the retinal pigment epidermis layer, which was filled with exudates and a few free pigment particles. Some cell nuclei of the outer nuclear layer are shrunk with solidification. Some cell nuclei are separated and dropped into the cavity gap. (2) There was bleeding beneath the retina; blood was filled beneath the retina, mixing with pigment blobs. Cells in the inner and outer nuclear layers are arranged randomly. It was clearly visible for necrosis of nuclei constricted with solidification. Cell bubbles of some nerve ganglia are formed or separated (and dropped) due to necrosis. (3) The retina was fractured and bleeding: all layers of the retina are fractured. Fracture was vwasible in cells of all layers due to necrosis with large amounts of free pigments. There was massive bleeding beneath the retina; blood drops into crystalline lens through fissures. The sizes of the foci were measured with a microscope: the retinal thickness of normal rabbits was 105μm ±2μm. In this experiment, the swollen height of retinal lesion foci was approximately 130 to 565μm; the foci diameter was approximately 225μm to 1.15mm.

IV. Discussion

Laser effect on eye injury, especially the threshold value of eye injury, was related to multiple factors. There are different effects with respect to the laser wavelength, emission type, pulse width, pulse number, size of light spots and kind of illuminated object, illuminated site, and pupil size.

Due to different illuminating levels, there are different injury intensities. Following are the results of quantitative analysis of the relationship between retinal injury intensities and illumination levels: the threshold value of retinal coagulation bleeding was 361μJ/cm^2; the threshold value of exclusive bleeding was 481μJ/cm^2. The ratio of two threshold values was 1:1.3; the difference between two threshold values was

$120\mu J/cm^2$. Thus, we can see that with increasing illumination levels, the retinal injury intensities increased. The retinal injury appears, starting with coagulation alone, to combined coagulation and bleeding, until all injuries are bleeding injuries.

Due to different pulse widths, there are different retinal injury threshold values. In this experiment, the injury threshold value of giant pulse was $100\mu J/cm^2$, but the threshold value of long pulses was in the millijoule order of magnitude per square centimeter [1, 2]. In the case of the ruby laser with a pulse width of 0.7ms, the threshold value of retinal injury was $16.61mJ/cm^2$. In another case of long pulses (0.6ms in pulse width) using the same equipment as this experiment, the threshold value of rabbit retinal injury was $14.9mJ/cm^2$. Both threshold values are greater by a factor of 40 to 45 than the threshold value obtained in this experiment. This explains the fact that the eye injury threshold value of the giant pulse laser was lower than that for the long pulse due to high peak power.

In addition, there are different injury threshold values for different kinds of eyes. Some authors report that the lowest threshold value of rabbit retinal coagulation injury was $8\mu J$; it was $22\mu J$ for monkeys, and $68\mu J$ for man [3, 4]. This explains that instances of injury in human and monkey eyes are higher than those for rabbit eyes. Other authors report that the level for massive bleeding in monkey eyes was $3.4mJ/cm^2$ [5]. In this experiment, the intensity of all bleeding injuries in rabbit retina was $704\mu J/cm^2$. The ratio between two levels was 4.8.

There are also different threshold values of laser eye injury. This was because the dioptric medium of the eye produces different transmissivities with respect to lasers of different wavelengths, and different absorptivities for the retina. For example, the transmissivity of the dioptric medium for the ruby

laser (694.3nm in wavelength) was approximately 96%; the effective absorptivity of the retina was approximately 53.7%. The effective absorptivity was lower (65.1%) than for green light [6]. Therefore, the threshold value of retinal damage by laser was higher than that of green light. In the case of 530nm YAG Q-switched double-frequency laser with its 8ns pulse width, the rabbit retinal injury threshold value was 232.05μJ/cm^2 [7]; for 5ns pulse width, the threshold value was 39.2μJ/cm^2 [8]. The injury threshold value for ruby laser was higher than these values.

It was generally considered that there are four main factors for retinal injury caused by the laser of visible-light wave band: the effect of heat, mechanical damage, the electromagnetic field effect, and optochemical damage. There are different effects of a laser at different wavelengths and pulse widths. As experimentally confirmed by the authors [9], the heat effect was apparently the cause of damage by long pulse non-Q-switched ruby laser. Most likely, mechanical damage was caused by the giant pulse Q-switched ruby laser. This was because an explosion from giant pulse produces a high-pressure surface, which forms a shock wave, leading to physical shifting and fracture of tissue cells. Therefore, after such laser illuminates onto retina, bleeding easily occurs. For example, bleeding injury in the rabbit retina was caused by long pulse ruby laser with level at 1024mJ/cm^2 [10]. The level was 704μJ/cm^2 in this experiment. It was apparent that the giant pulse laser easily causes bleeding retinal injury. The pathological observation of the injury reveals a similar effect by the long-pulse laser; however, there was random arrangement of cell shifting at the inner and outer nuclear layers, and damage on nerve-ganglionic cells was more severe than for long pulses. The phenomenon of the gasification zone in the gap beneath the retina was unclear. This reveals that the shock-wave effect by giant pulses was greater than that for long pulses.

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